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Reliability and Failure Modes of a Hybrid Ceramic Abutment Prototype

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Abstract

A ceramic and metal abutment prototype was fatigue tested to determine the probability of survival at various loads. Accelerated life testing employed. The abutment prototype comprised a metal sleeve fixture attachment with a ceramic transcutaneous component. Purpose: The research hypothesis was that the hybrid lithium disilicate ceramic/metal abutment survival would be limited by the failure of the metal abutment/fixture connection as found in all metal abutment/fixture systems. Materials and Method: Lithium disilicate CAD-milled abutments (n=24) were cemented to titanium sleeve inserts and then screw attached to titanium fixtures. The assembly was then embedded at a 30 degree angulation in polymethylmethacrylate. Each (n=24) was restored with a resin cemented machined lithium disilicate all ceramic central incisor crown. Single load (lingual-incisal contact) to failure was determined for three specimens. Fatigue testing (n=21) was conducted employing the step-stress method with lingual mouth motion loading. Failures were recorded and reliability calculations were performed using proprietary software (Alta PRO, Reliasoft). Probability Weibull curves were calculated with 90% confidence bounds. Fracture modes were classified with a stereomicroscope and representative samples imaged with scanning electron microscopy. Results: Fatigue results indicated that the limiting factor in the current design is the fatigue strength of the abutment screw, where screw fracture often leads to failure of the abutment metal sleeve and/or cracking in the implant fixture. Reliability for completion of a mission at 200 N load for 50K cycles was 0.38 (0.52-0.25 90% Confidence Interval) and for 100K cycles was only 0.12 (0.31-0.00) – only 12% predicted to survive. These results are similar to those from previous studies on metal to metal abutment/ fixture systems where screw failure is a limitation. Conclusion: No ceramic crown or ceramic abutment initiated fractures occurred, supporting the research hypothesis. The limiting factor in performance was the screw failure in the metal to metal connection between the prototyped abutment and the fixture indicating that this configuration should function clinically with no abutment ceramic complications..

Key Words: Fatigue, ceramics, abutment, lithium-disilicate

Introduction

Restoring implants in the esthetic zone can be a challenge for clinicians(1). Ceramic abutments, particularly zirconia (Y-TZP), were developed to allow improved esthetics. (2) However, concerns related to strength and fatigue resistance when compared to metal abutments have been raised with a recent laboratory study indicating the superiority of the titanium systems compared to range of zirconia abutment to metal approaches. (3) This Muhleman et study (3) evaluated the strength (bending moment) to failure of four zirconia abutment to metal fixture systems with an IPS Empress CAD crown following low load (49 N) high cycle fatigue (1,200,000 cycles). There was no significant difference between the four zirconia abutment designs. In some instances the all-ceramic crown fractured. On inspection almost all failures originated at the zirconia abutment to fixture interface. Failures occurred at low bending moments, particularly when compared to all metal systems where screw failure at much higher loads is the norm. (4, 5) Therefore, alternative ceramic-metal abutment concepts have significant interest and potential to impact oral implant therapy as a result of the projected increases in the overall system mechanical performance while maintaining good esthetics.

This investigation evaluated the fatigue reliability and fracture patterns of a lithium disilicate ceramic and metal abutment prototype. The system combines a metal sleeve insert in the implant fixture with a transcutaneous fluorescent lithium disilicate contoured abutment cemented to the sleeve. The screw retained metal sleeve is proposed to provide a high strength interface to the fixture as compared to an all ceramic abutment. An all-ceramic lithium disilicate crown was the restoration. The intent was to compare the fatigue reliability of the all-ceramic crown and modified abutment to previous work where an all

metal crown was placed on a titanium abutment and the limiting factor in the fatigue life was the abutment screw. (4, 5) This study assumed the research hypothesis that a hybrid lithium disilicate ceramic abutment prototype would have sufficient fatigue resistance to have survival limited by the abutment/fixture connection as found for metal/metal connections which have a reliability of approximately 0.5 for completion of a mission of 200 N load and 50K cycles – 50% survival. (4, 5)

Materials and Methods

Sample Preparation:

A 4.3 mm diameter tri-lobed titanium implants (Implant Direct, Nobel Biocare, Goteborg, Sweden) were used for this study (n=24). The implant fixtures were mounted in a cylindrical 1-inch diameter polycarbonate tube with orthodontic acrylic resin (PMMA) at a 30 degree angle to the long axis of the polycarbonate mounting tube (Figure 1). Lithium disilicate CAD/milled abutments prototypes (E.max, Ivoclar Vivadent, Schaan, Liechtenstein [hereafter Ivoclar]) were fabricated and cemented to titanium sleeves (milled from Implant Direct abutments) (n=24) with resin cement (Multi-link Implant Cement, Ivoclar). The prototype abutments (n=24) were positioned on each respective implant fixture and the retaining screw hand-torqued to 30 N/cm using a conventional torque driver. Lithium disilicate CAD/milled crowns (E.max) (n=24) with standard dimensions of a central incisor were produced and cemented to the abutments with a self-adhesive resin-based cement (Multi-link, Ivoclar). Samples were stored in distilled water at 37°C for at least seven days to assure total hydration of the cement and embedding material prior to testing.(6)

Single Load to Failure:

Following at least 7-days aging three specimens underwent ultimate fracture strength testing to establish the baseline value failure load for fatigue testing. Load was applied with a 6.25 mm tungsten carbide (WC) sphere (simulating an opposing tooth contact) 2

mm cervical to the lingual incisal edge and centered from mesial to distal. Testing was performed using a universal testing machine (Instron Model 5566, MN, USA) at a constant loading rate of 0.5 mm/min. The crown/abutment/implant samples (n=3) were loaded at a 30-degree angle (ISO 14801) until failure of one of the components (Figure 1). (4)

Fatigue Reliability Evaluation:

The fatigue step/stress specimens employed the same specimen and indenter geometric configuration. A mouth motion uniaxial loading system using a 6.25 mm diameter WC ball was employed at approximately 2 Hz (ELF 3300 Bose electro system, MN, USA) until specimen failure or survival occurred. (7-9) Failure was determined from load drops, acoustic events, and/or visible light-stereomicroscope observation of cracking or deformation following each load step. The visual inspection of all samples was conducted under polarized light to aid in crack detection and crack propagation imaging. (10)

The step-stress profile maximum load to be applied was approximately 50% of the mean of the single load to failure results. All of the remaining specimens (n=21) were distributed across 3 step-stress fatigue profiles (Figure 2). The mouth motion applied load and number load cycles numbers increased in a mild, moderate and aggressive manner. Specimens were distributed across the three profiles in the ratio of 4:2:1, mild to aggressive, respectively as is accepted in reliability testing field. (11, 12) The aggressive profile was defined first based upon the single load to failure mean and is shown in Figure 2. This profile has a maximum load of 450 N and totals 50,000 cycles. Based upon the first two failures utilizing this profile the other two profiles were prepared (Figure 2). The distribution of the specimens across three profiles permits calculation of a master Weibull Probability Curve that allows estimation of the probability of survival (reliability with confidence bounds) for a given load and number of load cycles (defined as the mission). (12)

Reliability analysis was performed (Alta 7 Pro, and Weibull ++7, Reliasoft, Tuscon, AZ) providing the probability of survival as a function of load at a mission of 50,000 and 100,000 load cycles.

A bending moment calculation was not performed as care was taken to apply the load at the same position on each sample (within a 0.25 mm radius). Based upon the distance from load application to the abutment fixture lingual junction (10.8 mm) the bending moment load can be determined but this was not entered into the calculation. This was the same loading distance and crown configuration as used in previous studies (4, 5) from our laboratory permitting a comparison between these and our results. Findings were recorded as load, number of cycles and step-stress profile in which the sample failed during accelerated life testing for the reliability calculations.

Post-Failure Analysis:

Failed/fractured specimens were stereomicroscope inspected to determine failure modes either between steps or after fracture occurred. Selected representative specimens were imaged in the SEM to further establish the fatigue failure patterns.

Results

Single Load to Failure:

The mean load to failure of the 3 specimens was 1005 ± 65 N. The specimens tested in this manner exhibit two failure modes, either catastrophic failure of the ceramic crown and ceramic abutment (2 instances, Figure 3) or screw bending (Figure 4).

Reliability Evaluation (Step-stress Fatigue):

Specimens (n=3) were first run in the Aggressive Profile. Two failed at 250 N before completion of 20K cycles (one at 3,667 and the other at 16,186). The other specimen at 22,228 cycles at 300 N. The polarized light microscopic inspection found that in the first two instances the screw fractured as well as the abutment metal below the lobes (Figure 4) and in the third the screw shaft to screw head junction failed.

Based upon the aggressive profile results the mild and moderate profiles were designed (Figure 2). Subsequently specimens were run in these conditions with 12 in the mild and 6 in the moderate groups. The majority of the failures occurred in the range of 180-280 N at varying numbers of cycles.

Readily apparent across all profiles was that almost every failure included screw failure (n=18) or screw bending (n=2). Screw fractures were either at the level of the screw threads near the depth of the abutment lobes (Figure 4) or at the screw head-thread junction (at the base of the drilling for the internal connection) (Figure 4) which is above the level of the lobe sleeve junction of the abutment. An example of the fixture cracking is shown in Figure 5.

The step-stress reliability was calculated using a power model for damage accumulation. Testing for the best fit distribution it was found that a lognormal calculation was the most appropriate (Fig 6). This might be because of competing failure modes. Note that fitting a Weibull distribution resulted in a Weibull modulus near one ($m=1.4$) indicating that fatigue, as tested across the three profiles, did not appreciably accelerated failure. This Weibull result may be related to competition between two different failure modes (Weibull curve concave downward) resulting in the lognormal distribution best fitting the strength data in this complex system. Microscopic inspection indicated that none of the failures appeared to be associated with the abutment ceramic or the all-ceramic crown.

Using the lognormal distribution shown in Figure 6 we calculated the reliability of the system for survival at various load levels for a mission of 50,000 or 100,000 cycles as shown in the Table. Note the large decrease in the reliability (probability of survival) when the fatigue load is increased from 150 to 200 N. This was true whether the mission was to complete 50,000 or 100,000 cycles.

Discussion

Our results indicate that the ceramic metal abutment system as tested is limited by the abutment screw strength and metal fixture design and strength. The ceramic and metal

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system along with their prosthetic parts above the abutment to fixture junction, appears 100% reliable for 100K cycles at the highest load applied in our test configuration (280 N). Based upon review of the failure modes of the 20 fatigued specimens which consistently exhibited abutment screw fracture, it is apparent that the probability of survival of the reconstruction was chiefly compromised by its design and failure rate over time. Most commonly, abutment screw failure lead to sleeve metal fracture and in several instances to cracking of the implant fixture. It cannot be ruled out that fixture microcracking may lead to screw movement, bending and eventually its failure as noted in Figure 5.

The fatigue failures indicate that the abutment/metal fixture design transfers a significant stress to the screw leading to its failure. (5, 13) The ceramic crown and ceramic portion of the abutment were not involved. A previous study has shown the limits of screw design in 3 implant systems with related geometry. (5) All systems would benefit from a screw made of a higher strength alloy and/or a modified configuration. The reliability shown in the Table for a mission of 200 N and 50,000 cycles can be considered as as a bit low compared to previous work where the reliability for this same mission ranged from 0.61-0.8. (4, 5) However, we are not aware of any clinical reports of problems associated with abutment screw fractures with the Implant Direct System evaluated herein. Similarly, the Replace Select and Intra-Lock International (4), the IC IMP Osseotite, and Unitive systems (5) previously fatigue tested and shown to be limited in reliability by abutment screw/fixture failures have not been noted as having poor clinical performance. We are not aware of any studies that have been able to specify a minimum fatigue strength or reliability target for an abutment and fixture system to assure clinical success.

In our study loading was applied to the middle of the mesio-distal dimension of the lingual surface and 2 mm below the incisal. As such this creates an axially aligned bending moment. The results might be different if a torsional component was induced by loading at the mesial or distal marginal ridge.

We utilized an accelerated life time approach, step-stress testing, in this fatigue study. Step-stress accelerated life testing is widely used in the aircraft, automotive and

electronics industries to compare lifetimes of different design configuration or modifications. (11) This approach was introduced to implant dentistry only recently (14) but has been shown to agree with clinical findings in studies of all-ceramic crowns. (7, 15)

Conclusion

Within the limitations of the present experiment, the following was concluded:

The combined ceramic with titanium sleeve abutment prototype performance was limited by the fatigue degradation of the abutment screw. In fatigue, no ceramic crown or ceramic abutment components failed supporting the research hypothesis with a reliability similar to that of all metal abutment fixture systems. A lithium disilicate abutment with a Ti alloy sleeve in combination with an all-ceramic crown should be expected to function clinically in a satisfactory manner.

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References

1. Kutkut A, Abu-Hammad O, Mitchell R. Esthetic Considerations for Reconstructing Implant Emergence Profile Using Titanium and Zirconia Custom Implant Abutments: Fifty Case Series Report. *J Oral Implantol*. 2013.
2. Sailer I, Zembic A, Jung RE, Hammerle CH, Mattiola A. Single-tooth implant reconstructions: esthetic factors influencing the decision between titanium and zirconia abutments in anterior regions. *Eur J Esthet Dent*. 2007;2(3):296-310.
3. Muhlemann S, Truninger TC, Stawarczyk B, Hammerle CH, Sailer I. Bending moments of zirconia and titanium implant abutments supporting all-ceramic crowns after aging. *Clin Oral Implants Res*. 2014;25(1):74-81.
4. Freitas AC, Jr., Bonfante EA, Martins LM, Silva NR, Marotta L, Coelho PG. Reliability and failure modes of anterior single-unit implant-supported restorations. *Clin Oral Implants Res*. 2012;23(9):1005-11.

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5. Martins LM, Bonfante EA, Zavanelli RA, Freitas AC, Jr., Silva NR, Marotta L, et al. Fatigue reliability of 3 single-unit implant-abutment designs. *Implant Dent.* 2012;21(1):67-71.
6. Coelho PG, Silva NR, Bonfante EA, Guess PC, Rekow ED, Thompson VP. Fatigue testing of two porcelain-zirconia all-ceramic crown systems. *Dent Mater.* 2009;25(9):1122-7.
7. Coelho PG, Bonfante EA, Silva NR, Rekow ED, Thompson VP. Laboratory simulation of Y-TZP all-ceramic crown clinical failures. *J Dent Res.* 2009;88(4):382-6.
8. Freitas Junior AC, Bonfante EA, Silva NR, Marotta L, Coelho PG. Effect of implant-abutment connection design on reliability of crowns: regular vs. horizontal mismatched platform. *Clin Oral Implants Res.* 2012;23(9):1123-6.
9. Freitas-Junior AC, Almeida EO, Bonfante EA, Silva NR, Coelho PG. Reliability and failure modes of internal conical dental implant connections. *Clin Oral Implants Res.* 2013;24(2):197-202.
10. Silva NR, Bonfante EA, Rafferty BT, Zavanelli RA, Rekow ED, Thompson VP, et al. Modified Y-TZP core design improves all-ceramic crown reliability. *J Dent Res.* 2011;90(1):104-8.
11. Madi MT. Step-Stress Accelerated Life Tests. In: Lovric M, editor. *International Encyclopedia of Statistical Science*: Springer Berlin Heidelberg; 2014. p. 1514-7.
12. Nelson W. *Accelerated testing: statistical models, test plans and data analysis*. New York: John Wiley & Sons; 2004.
13. Freitas-Junior AC, Rocha EP, Bonfante EA, Almeida EO, Anchieta RB, Martini AP, et al. Biomechanical evaluation of internal and external hexagon platform switched implant-abutment connections: An in vitro laboratory and three-dimensional finite element analysis. *Dent Mater.* 2012;28(10):e218-28.
14. Silva NR, Coelho PG, Fernandes CA, Navarro JM, Dias RA, Thompson VP. Reliability of one-piece ceramic implant. *J Biomed Mater Res B Appl Biomater.* 2009;88(2):419-26.
15. Silva NR, Bonfante EA, Zavanelli RA, Thompson VP, Ferencz JL, Coelho PG. Reliability of metaloceramic and zirconia-based ceramic crowns. *J Dent Res.* 2010;89(10):1051-6.

Table:

Table: Reliability for a mission of a) 50,000 and b) 100,000 cycles at specified load using the lognormal probability curve with 90% confidence bounds. Overlaps between upper and lower limits represent groups with similar behavior.

	150 N	200 N	250N
a) 50,000 cycles			
Upper 90% CB	0.98	0.52	0.12
Reliability	0.94	0.38	0.04
Lower 90% CB	0.83	0.25	0.01
b) 100,000 cycles			
Upper 90% CB	0.89	0.26	0.03
Reliability	0.74	0.12	0.00
Lower 90% CB	0.52	0.05	0.00

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Figures:

Figure 1: Implant fixtures mounted in a cylindrical 1-inch diameter polycarbonate tube with orthodontic acrylic resin at a 30 degree angle to the long axis.

Figure 2: Step-stress profiles plots representing the aggressive, mild and moderate profiles in which samples were distributed across being $n=9$, $n=6$ and $n=3$ respectively.

Figure 3: (A-D) Single load to failure at 996 N crown and abutment ceramic fracture (with evidence of some screw bending). E-G Single load to failure with screw bending noted at 944 N. Lingual views with baseline image in the center and the failed specimen to the and right (segmented arrow).

Figure 4: (A-C) Aggressive profile failure at 3,667 cycles at 250 N. Screw fracture and metal abutment failure at the level of the abutment alignment lobes. (D-F) Sample failure at 198,085 cycles and 250 N load (mild profile). Note in the stereomicroscope image that the screw threads extend above the fixture to the level of the lobes. The view to the right shows the hex head drill hole extending to the head-thread junction where the fatigue failure occurred.

Figure 5: Implant fixture fracture believed to be secondary to screw failure (segmented circle).

Figure 6: Use level probability curve using a lognormal distribution fit at a use load of 200 N. Based upon this calculations to derive this curve the reliability of the system for survival at various load levels for a mission of 50,000 and 100,000 cycles can be calculated as depicted in Table 1.











